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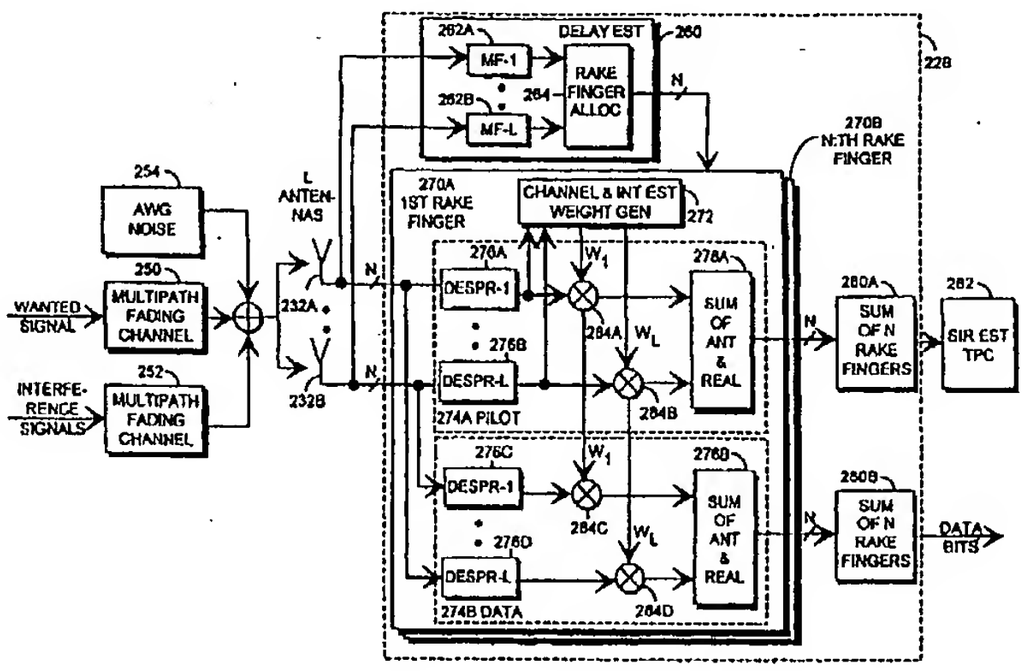

(57) Abstract

The invention relates to a RAKE receiver of a CDMA system using IRC, the receiver receiving a radio signal by using at least two antenna branches (232A, 232B). In accordance with the invention, a RAKE finger (270A, 270B) comprises: a weighting coefficient part (272) for forming weighting coefficients maximizing the Signal–to–Interference–and–Noise Ratio (SINR) for each antenna branch (232A, 232B); a multiplier (284A, 284B) for multiplying a pilot part (274A), despread by a despreader (276A, 276B) in each antenna branch (232A, 232B), by a weighting coefficient; a multiplier (284C, 284D) for multiplying a data part (274B), despread by a despreader (276C, 276D) in each antenna branch (232A, 232B), by a weighting coefficient; an antenna branch summer (278A) for combining the despread pilot parts (274A), received via the separate antenna branches (232A, 232B) and multiplied by the weighting coefficient, to one pilot signal; an antenna branch summer (278B) for combining the despread data parts (274B), received via the separate antenna branches (232A, 232B) and multiplied by the weighting coefficient, to one data signal. In addition, the receiver comprises a RAKE finger summer (280B) for combining the data signals of the RAKE fingers (270A, 270B) operating by different delays to a sum data signal representing the received bits.

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RAKE RECEIVER

FIELD OF THE INVENTION

The invention relates to a RAKE receiver of a radio system using a Code Division Multiple Access (CDMA) method.

BACKGROUND OF THE INVENTION

In radio systems, diversity methods of different kinds are used for increasing the coverage area and/or capacity of the system. As to this publication, space diversity, i.e. antenna diversity, polarization diversity and multipath diversity are of interest. Space diversity signifies that antennas are positioned sufficiently far from each other to achieve a sufficient decorrelation between signals received via the separate antennas. An interesting kind of polarization diversity is implicit polarization, when a signal is sent on one polarization level, but received by cross-polarized antennas. Multipath diversity signifies a diversity created by multipath propagated signal components, this diversity being usable in a system, such as a CDMA system, in which the bandwidth of a signal is much wider than the coherent bandwidth of a channel.

In a CDMA system, a RAKE receiver is used for separating multipath propagated signal components at the reception. In general, the signal components must then be separated from each other at least by one part of a spreading code used, i.e. by a chip. The RAKE receiver comprises RAKE fingers and, in each of these fingers, despreading and diversity combination take place. In addition, the receiver comprises a delay estimator having a matched filter for each antenna branch and an allocation block for the RAKE fingers. In the matched filter, a signal, received by a spreading code used for signal spreading, is correlated by different delays, the timing of the spreading code then being changed for instance in steps of one chip. When the correlation is high, a multipath propagated signal component is found, which can then be received by the delay found.

On the radio path, the signal will include, besides the wanted signal, also noise and interference caused by other users or systems. In systems utilizing diversity, the influence of noise and interference can be decreased for instance by Maximal Ratio Combining (MRC) method, according to which method signals received via separate antennas are weighted in proportion to the signal power in the separate antenna branches. However, this method

presupposes that the interference of each antenna is independent. This presupposition is not always true in practical cellular radio networks, but it is conceivable that the same interference is present at each antenna.

There is no such restriction on Interference Rejection Combining (IRC) method. However, the method has been used only in systems utilizing Time Division Multiple Access (TDMA) method, these systems often being incapable of separating multipath propagated signal components. IRC method signifies here an adaptive beam forming (optimal combination of signals), by which the signal power is maximized in proportion to the power of interference and noise, i.e. a Signal-to-Interference-and-Noise Ratio (SINR) is maximized.

BRIEF DESCRIPTION OF THE INVENTION

The object of the invention is thus a RAKE receiver using IRC. This is achieved by the RAKE receiver presented below. This RAKE receiver comprises at least two antenna branches for receiving a radio signal; at least one RAKE finger connected to the antenna branches for processing a multipath propagated signal component of the radio signal; a delay estimator connected to the antenna branches for searching for a delay of at least one multipath propagated signal component and for allocating a RAKE finger for processing the found multipath propagated signal component and for informing said RAKE finger of the found delay; the RAKE finger comprising: a channel estimator for generating an impulse response of the channel of the multipath propagated signal component found by means of a known pilot part included in the radio signal of each antenna branch; an interference estimator for generating an interference signal, included in the radio signal of each antenna branch and consisting of interference and noise, by subtracting from the received radio signal a regenerated wanted radio signal, which regenerated wanted radio signal is obtained by means of the known pilot part and the estimated impulse response of the channel; a despreader connected to each antenna branch for despreading the pilot part included in the multipath propagated signal component by using a known spreading code by a delay as informed by the delay estimator; a despreader connected to each antenna branch for despreading the data part included in the multipath propagated signal component by using the known spreading code by a delay as informed by the delay estimator. The RAKE finger also comprises: a weighting coefficient

part for providing each antenna branch with weighting coefficients maximizing the Signal-to-Interference-and-Noise Ratio (SINR); a multiplier for multiplying the pilot part, despread by the despreader in each antenna branch, by a weighting coefficient; a multiplier for multiplying the data part, despread by the despreader in each antenna branch, by a weighting coefficient; an antenna branch summer for combining the despread pilot parts, received via the separate antenna branches and multiplied by the weighting coefficient, to one pilot signal; an antenna branch summer for combining the despread data parts, received via the separate antenna branches and multiplied by the weighting coefficient, to one data signal; and the RAKE receiver further comprises a RAKE finger summer for combining the data signals of the RAKE fingers operating by different delays to a sum data signal representing the received bits.

Objects of dependent claims are presented in the preferred embodiments of the invention.

The invention is based on that a RAKE receiver using IRC is formed.

The RAKE receiver of the invention provides the E_b/I_0 ratio of a signal (energy per bit divided by power density of interference) with a value up to two decibels better than a conventional RAKE receiver using MRC.

BRIEF DESCRIPTION OF THE FIGURES

The invention will now be described in greater detail by means of preferred embodiments, with reference to the attached drawings, in which

Figures 1A and 1B illustrate a mobile telephone system;

Figure 2A shows a transmitter and a receiver of a mobile telephone system;

Figure 2B illustrates spreading and modulation in a transmitter;

Figure 2C illustrates the solution of the invention to a combined descrambling, decoding and demodulation block of the receiver of Figure 2A;

Figure 3 illustrates channels of a mobile telephone system positioned in a frame;

Figure 4 illustrates the structure of user equipment in a simplified manner.

DETAILED DESCRIPTION OF THE INVENTION

The invention may be applied to mobile telephone systems of different kinds, using Code Division Multiple Access (CDMA) method. The examples illustrate the use of the invention in a universal mobile telephone system utilizing a direct sequence broadband code division multiple access method; without the invention being restricted to this, however. Thus, for instance the mobile telephone system IMT-2000 developed by ARIB (Association of Radio Industries and Businesses) in Japan and the Universal Mobile Telephone System (UMTS) to be developed in Europe are systems in accordance with the invention. The examples are based on the description of WCDMA system, additional information being available in an ETSI (European Telecommunications Standards Institute) specification "The ETSI UMTS Terrestrial Radio Access (UTRA) ITU-R RTT Candidate Submission (Tdoc SMG2 260/98, May/June 1998)" referred to herein.

The structure of a universal mobile telephone system is explained referring to Figures 1A and 1B. Figure 1B comprises only the blocks that are essential for the description of the invention, but it is obvious to one skilled in the art that a conventional mobile telephone system also comprises other functions and structures, which need not be explained here in more detail. The main parts of a mobile telephone system are a Core Network CN, a UMTS terrestrial radio access network UTRAN and User Equipment UE. The interface between CN and UTRAN is called Iu and the air interface between UTRAN and UE is called Uu.

UTRAN comprises Radio Network Subsystems RNS. The interface between the RNSs is called Iur. An RNS comprises a Radio Network Controller RNC and one or more nodes B. The interface between RNC and B is called Iub. The coverage area of node B, i.e. a cell, is designated C in Figure 1B.

The description of Figure 1A is very abstract, and therefore, it is clarified in Figure 1B by showing which part of the GSM system approximately corresponds to which part of the UMTS. It shall be noted that the mapping presented is not in any way binding, but indicative, because the responsibilities and functions of the various parts of the UMTS are still under development.

In accordance with Figure 1B, a circuit-switched connection can be established from user equipment UE to a telephone 100 connected to a Public Switched Telephone Network (PSTN) 102. User equipment UE can be for in-

stance a fixed terminal, a terminal positioned in a vehicle or a portable terminal. The radio network infrastructure UTRAN comprises radio network subsystems RNS, i.e. base station systems. A radio network subsystem RNS comprises a radio network controller RNC, i.e. a base station controller, and at least one node B, i.e. a base station, controlled by that controller.

A base station B comprises a multiplexer 114, transceivers 116 and a control unit 118 controlling the operation of the transceivers 114 and the multiplexer 116. Traffic and control channels used by a plurality of transceivers 114 are positioned on a transmission link lub by the multiplexer 116.

From the transceivers 114 of the base station B, there is a connection to an antenna unit 120 implementing a bidirectional radio connection Uu to user equipment UE. The structure of frames to be transmitted on the bidirectional radio connection Uu is accurately defined.

The base station controller RNS comprises a switching network 110 and a control unit 112. The switching network 110 is used for connecting speech and data and for combining signalling circuits. The base station system constituted of the base station B and the base station controller RNC additionally comprises a transcoder 108. The division of tasks between the base station controller RNC and the base station B and the physical structure thereof may vary as per implementation. The base station B typically attends to the implementation of the radio path in the above-described manner. The base station controller RNC typically controls things as follows: radio resources, handover between cells, power control, timing and synchronization, paging of user equipment.

The transcoder 108 is generally situated as close to a mobile phone exchange 106 as possible, because speech then can be transmitted in the form of a mobile phone system between the transcoder 108 and the base station controller RNC by saving transmission capacity. The transcoder 108 converts the various digital speech coding forms between the public switched telephone network and the radio telephone network into compatible, for instance from a 64 kbit/s form of a fixed network to another (for instance 13 kbit/s) form of the cellular radio network and vice versa. The devices required are not described here any further, but it can be stated that no other data than speech is converted by the transcoder 108. The control unit 112 performs call control and mobility management, collects statistic data and performs signalling.

A core network CN is constituted of an infrastructure belonging to a mobile telephone system outside the UTRAN. Of the devices of the core network CN, Figure 1B illustrates the mobile phone exchange 106 and a gateway mobile phone exchange 104, attending to the connections of the mobile phone system to the outside world, here to the public switched telephone network 102.

Figure 4 shows an example of the structure of user equipment UE. The substantial parts of user equipment UE are: an interface 404 for an antenna 402 of user equipment, a transceiver 406, a control part 410 of user equipment and an interface 412 for a battery 414. A user interface generally comprises a display 400, a keyboard 408, a microphone 416 and a loudspeaker 418. User equipment may be for instance a portable mobile phone, a phone to be positioned in a car, a terminal of wireless local loop or data transmission equipment integrated into a computer.

Figure 2A illustrates the function of a pair of radio transceivers. A radio transmitter may be located in a node B or in user equipment UE and a radio receiver in user equipment UE or in the node B.

The upper part of Figure 2A shows the essential functions of a radio transmitter. Various services to be located on a physical channel are for instance speech, data, moving or stopped video image and control channels of the system. The figure illustrates control channel and data processing. The various services require various source coding means; speech, for instance, requires a speech codec. For the sake of clarity, the source coding means are not shown in Figure 2A, however.

Pilot bits used by the receiver for channel estimation are also located on the control channel 214. User data 200 are located on the data channel.

The various channels are then channel-coded in various ways in blocks 202A and 202B. Channel coding comprises for instance different block codes, an example of them being Cyclic Redundancy Check (CRC). In addition, convolution coding and its various modifications, such as punctured convolution coding or turbo coding, are typically used. Said pilot bits are not channel coded, however, because the intention is to find out the signal distortions caused by the channel.

After the various channels have been channel coded, they are interleaved in an interleaver 204A, 204B. The aim of interleaving is to facilitate

error correction. At interleaving, the bits of the various services are scrambled together in a predetermined way, whereby an instantaneous fading on the radio path alone does not necessarily make the transmitted information unfit for identification. Subsequently, the interleaved bits are spread by a spreading code in blocks 206A, 206B. The chips obtained are then scrambled by a scrambling code and modulated in block 208, the operation of which is described in more detail in Figure 2B. In this way, the separate signals are combined in block 208 to be transmitted via the same transmitter.

Finally, the combined signal is brought to radio frequency parts 210, which may comprise different power amplifiers and bandwidth restricting filters. Regulation of a closed loop used for transmission power control generally controls a transmission power control amplifier located in this block. An analog radio signal is then sent via the antenna 202 to the radio path Uu.

The lower part of Figure 2A illustrates the essential functions of a radio receiver. The radio receiver is typically a RAKE receiver. An analog radio frequency signal is received from the radio path Uu by an antenna 232. The signal is brought to radio frequency parts 230 comprising a filter, which prevents frequencies outside the desired frequency band.

Subsequently, the signal is converted in block 228 to an intermediate frequency or directly to baseband, in which form the signal is sampled and quantized. Because the signal is a multipath propagated signal, the intention is to combine the signal components propagated along different paths in block 228, the block comprising the actual RAKE fingers of the receiver according to the prior art technique. Block 228 is described in more detail in Figure 2C.

The obtained physical channel is then deinterleaved in a deinterleaver 226. Subsequently, the deinterleaved physical channel is divided into data streams of different channels in a demultiplexer 224. Each channel is brought to a separate channel decoding block 222A, 222B, where the channel coding used for a transmission, such as block coding and convolution coding, is decoded. Convolution coding is decoded preferably by a Viterbi decoder. Each transmitted channel 220A, 220B can then be brought to be further processed, as needed, for instance data 220 is brought to a computer 122 connected to user equipment UE. The control channels of the system are brought to a control part 236 of the radio receiver.

Figure 2B illustrates in more detail how a channel is spread by a spreading code and modulated. To the left in the figure, a bit stream of the

channel comes to block S/P, where each two-bit sequence is converted from series form to parallel form, which means that one bit is brought to branch I of the signal and the other one to branch Q of the signal. Subsequently, the signal branches I and Q are multiplied by a spreading code c_{ch}, whereby a relatively narrow-band information is spread to a wide frequency band. Each branch can have the same or a different spreading code. Each connection Uu has a separate spreading code or separate spreading codes, by which the receiver identifies the transmissions intended for it. Then the signal is scrambled by multiplying it by a scrambling code $c_{I\ scramb} + j\ c_{Q\ scramb}$, being separate for each transmitter. The pulse form of the obtained signal is filtered by filters p(t). Finally, the signal is modulated to a radio frequency carrier by multiplying its separate branches shifted from each other by 90 degrees, the branches thus obtained are combined to one carrier ready to be sent to the radio path Uu, excluding possible filterings and power amplifications. The modulation mode described is Quadrature Phase Shift Keying QPSK.

Instead of the described I/Q multiplexing, time multiplexing can also be used, where data and control channels are positioned sequentially on time axis. However, the time difference between the channels is then so small that an interference estimated from the control channel can be assumed to be the same also on the data channel.

Maximally, two hundred and fifty six different mutually orthogonal spreading codes can typically be used simultaneously. For instance, if the UMTS uses a five megahertz carrier at the speed of 4.096 megachips per second in the downlink direction, the spreading factor two hundred and fifty six corresponds to the transmission speed of thirty two kilobits per second, and respectively, the highest practical transmission speed is achieved by spreading factor four, whereby the data transmission speed is two thousand forty eight kilobits per second. Accordingly, the transmission speed on the channel varies stepwise 32, 64,128, 256, 512,1024 and 2048 kbit/s, while the spreading factor varies 256, 128, 64, 32, 16, 8 and 4, respectively. The data transmission speed at the user's disposal depends on the channel coding used. For instance, if 1/3 convolution coding is used, the user's data transmission speed is about one third of the data transmission speed of the channel. The spreading factor informs the length of the spreading code. For instance, the spreading code corresponding to the spreading factor one is (1). The spreading factor two has two mutually orthogonal spreading codes (1,1) and (1,-1). Further, the

spreading factor four has four mutually orthogonal spreading codes: below an upper level spreading code (1,1), there are spreading codes (1,1,1,1) and (1,1,-1,-1), and below another upper level spreading code (1,-1), there are spreading codes (1,-1,1,-1) and (1,-1,-1,1). The formation of spreading codes is continued in this way when propagating to lower levels of a code tree. The spreading codes of a given level are always mutually orthogonal. Likewise, a spreading code of a given level is orthogonal with all the spreading codes of another spreading code of the same level, which are derived from that other spreading code to next levels.

In transmission, one symbol is multiplied by a spreading code, whereby the data spreads over the frequency band to be used. For instance, when the spreading code 256 is used, one symbol is represented by 256 chips. Respectively, when the spreading code 16 is used, one symbol is represented by 16 chips.

Figure 3 shows an example of which kind of frame structure can be used on a physical channel. Frames 340A, 340B, 340C,340D are numbered consecutively from one to seventy two and they form a 720 milliseconds long superframe. The length of one frame 340C is 10 milliseconds. The frame 340C is divided into sixteen slots 330A, 330B, 330C, 330D. The length of one slot 330C is 0.625 milliseconds. One slot 330C corresponds typically to one power control period, during which the power is controlled for instance by one decibel upwards or downwards.

The physical channels are divided into two different types: Dedicated Physical Data Channels (DPDCH) 310 and Dedicated Physical Control Channels (DPCCH) 312. The dedicated physical data channels 310 are used for transporting data 306 generated in layer two of Open Systems Interconnection (OSI) and above it, i.e. dedicated traffic channels, mainly. The dedicated physical control channels 312 transport control information generated in layer one of OSI. The control information comprises: a pilot part, i.e. pilot bits, 300 to be utilized for channel estimation, Transmit Power Control (TPC) commands 302 and, optionally, a Transport Format Indicator (TFI) 304. The transport format indicator 304 tells the receiver the transmission speed used at that moment by each dedicated physical data channel in the uplink direction.

As appears from Figure 3, the dedicated physical data channels 310 and the dedicated physical control channels 312 are time-multiplexed into the same slot 330C in the downlink direction. In the uplink direction again,

these channels are transmitted in parallel in such a way that they are IQ-multiplexed (I = Inphase, Q = Quadrature) into each frame 340C and transmitted by using dual-channel Quadrature Phase Shift Keying (QPSK) modulation. When the intention is to transmit additional dedicated physical data channels 310, they are code-multiplexed either into branch I or Q of the first pair of channels.

Subsequently, Figure 2C is examined, the figure illustrating in more detail the combined descrambling, decoding and demodulating block 228 of the receiver, shown in Figure 2A. Descrambling is not described, however, because it is of no relevance for the invention. A desired radio signal, sent to the radio path Uu, multipath propagates on an occasionally fading channel 250. Further, additive zero mean white gaussian noise 254 is combined with the signal. Moreover, interfering signals, also multipath propagating on an occasionally fading channel 252, are combined with the signal.

Consequently, a signal to be received from the radio path Uu contains, besides the wanted signal, also both noise and interference. The signal is received by using at least two separate antenna branches 232A, 232B. The branches 232A, 232B may form an antenna array to provide antenna gain, the separate antennas being relatively close to each other, at a distance of half a wavelength, for instance. Another possibility is that the branches 232A, 232B are diversity branches, the separate antennas being relatively far from each other, at a distance of 10 to 20 wavelengths, for instance. The diversity can be implemented as space or polarization diversity.

The example of Figure 2C illustrates the use of space diversity, the branches 232A, 232B being implemented as an adaptive antenna. The adaptive antenna is implemented by antennas 232A, 232B positioned far enough from each other, via which antennas the multipath propagated signal is received.

The number of antennas may be L. The figure illustrates only two antennas, the first antenna 232A and the Lth antenna 232B. The two points between the antennas represent the existing antennas, not described for the sake of clarity, however. Generally, the number of antennas varies between two and eight.

In accordance with the invention, signals received via the separate antenna branches 232A, 232B are weighted in such a way that the influence of noise and interference can be minimized.

When diversity is used, the intention is to make the correlation between the branches as low as possible. Another way of implementing diversity is to use polarization diversity, whereby a signal is received by cross-polarized antennas. In theory, also hybrids are possible, which means that both space and polarization diversity may be used simultaneously. As an example of a solution placeable in user equipment can be mentioned a so-called patch antenna, which can be a plate of about a square inch in size, the plate having cross polarization planes. Another example is user equipment positioned in a vehicle, where an implementation of space diversity also is relatively easy.

A signal received from all L antenna branches 232A, 232B is brought via radio frequency parts (not shown in Figure 2C) to a delay estimator 260 connected to the antenna branch 232A, 232B. In the delay estimator 260, the delays of the best audible multipath propagated signal components are searched for. A RAKE finger 270A, 270B is allocated for processing the found multipath propagated signal components. The delay estimator 260 informs each RAKE branch 270A, 270B of the found delay.

The delay estimator 260 comprises a matched filter 262A, 262B for each antenna branch 232A, 232B. Thus, the number of matched filters 262A, 262B is also L. In the matched filter 262A, 262B, a predetermined number of parallel correlation calculations is performed for the received radio signal by different delays in order to estimate the delays of the multipath propagated signal components. At correlation calculation, the spread pilot part contained in the received radio signal is despread by a known spreading code using a predetermined delay.

On the basis of the calculated correlations, an allocator 264 situated in the delay estimator selects at least one delay, by which a multipath propagated signal component is received. The allocator allocates a RAKE finger 270A, 270B for processing the found signal component by informing the RAKE finger of the found delay. To perform the selection, the correlation results of each matched filter 262A, 262B are typically combined in the allocator 264. If the correlation is high, a delay is found that represents the delay of the multipath propagated signal component of the radio signal coming to the antenna branch 232A, 232B in question. In general, the strongest multipath components have the same code phase at all antennas, which is due to the vicinity of the antennas and to the fact that radio signals propagate at the speed of light.

In practice, a predetermined number of RAKE fingers 270A, 270B, is allocated and/or a number required for delays exceeding a predetermined threshold value at correlation calculation. Generally, a limiting factor will be the maximum number of the used RAKE fingers 270A, 270B. In this example, the number of allocated RAKE fingers 270A, 270B is indicated by the letter N. The number of signal components depends on radio conditions and, for instance, on terrain shape and buildings causing reflections. In the most cases, the smallest delay by which multipath propagated signal components are searched for is one chip.

One RAKE finger 270A, 270B processes one multipath propagated signal component by a given code delay. The RAKE finger 270A, 270B comprises a channel estimator 272, by which a channel impulse response of a multipath propagated signal component, included in a radio signal and found by means of a known pilot part, i.e. practically complex impulse response taps of the channel, are generated.

In addition, the RAKE finger 270A, 270B comprises an interference estimator 272, by which an interference signal, included in a radio signal of each antenna branch 232A, 232B and consisting of interference and noise, is generated by subtracting from the received radio signal a regenerated wanted radio signal. The regenerated wanted radio signal is obtained by means of the known pilot part included in the radio signal and by means of the estimated impulse response of the channel.

The areas drawn with broken lines in Figure 2C illustrate the processing of the pilot part 274A included in the radio signal and the processing of the data part 274B included in the radio signal.

The RAKE finger 270A, 270B, comprises a despreader 276A, 276B, connected to each antenna branch 232A, 232B and despreading the spread pilot part 274A included in the multipath propagated signal component, by using a known spreading code by a delay informed by the delay estimator 260.

Correspondingly, the RAKE finger 270A, 270B comprises a despreader 276C, 276D, connected to each antenna branch 232A, 232B and despreading the spread data part 274B included in the multipath propagated signal component, by using a known spreading code by a delay informed by the delay estimator 260. There are L despreaders for processing both the data part and the pilot part, i.e. two per each antenna branch 232A, 232B in each RAKE finger 270A, 270B. In practice, when despreading, the data part or the

pilot part of the signal component is multiplied by a complex conjugate of the spreading code in the right phase.

As a whole, the situation is such that the delay estimator 260 allocates N RAKE fingers 270A, 270B, for the best audible signal components. In each RAKE finger 270A, 270B, L antenna branches 232A, 232B, are processed. Both the pilot part of the radio signal and the data part of the radio signal are processed separately. The number N may vary depending on circumstances, or a threshold value may be set for the level of the multipath propagated signal component. If this threshold value is exceeded, said RAKE finger 270A, 270B is noted and the reception continues. Consequently, searching for timing is a dynamic process, and so is the allocation of the RAKE fingers 270A, 270B to be combined.

A weighting coefficient part 272 in the RAKE finger 270A, 270B forms weighting coefficients maximizing the signal-to-interference-and-noise ratio (SINR) for each antenna branch 232A, 232B. This can be made for instance by multiplying an inverse matrix of a covariance matrix of an interference signal, consisting of interference and noise of the antenna branches 232A, 233B, by an estimated impulse response of the channel. The weighting coefficients are complex.

The pilot part 274A despread by the despreader 276A, 276B in each antenna branch 232A, 232B is multiplied by the obtained weighting coefficients by using a multiplier 284A, 284B located in the RAKE finger 270A, 270B. Correspondingly, the data part 274B despread by the despreader 276C, 276D in each antenna branch 232A, 232B is multiplied by the obtained weighting coefficients by using a multiplier 284C, 284D. Accordingly, the signal components including the pilot part and the signal components including the data part are multiplied by the same weighting coefficients separately.

An antenna branch summer 278A, positioned last in the RAKE finger 270A, 270B, combines the despread pilot parts 274A, received via the separate antenna branches 232A, 232B and multiplied by a weighting coefficient, to one pilot signal.

Correspondingly, an antenna branch summer 278B combines the despread data parts 274B, received via the separate antenna branches 232A, 232B and multiplied by a weighting coefficient, to one data signal.

The RAKE receiver additionally comprises a RAKE finger summer 280B combining the data signals of the RAKE fingers 270A, 270B functioning

by different delays to a sum data signal representing the received bits. The data bits are then brought according to Figure 2A from block 228 to block 226 to be deinterleaved.

The receiver presented is suitable for use both at a base station and at user equipment. This means that both I/Q multiplexing and time multiplexing of data channel and control channel are possible.

Between the antenna branch summer 278A, 278B and the RAKE finger summer 280A, 280B, there may be a real part 278A, 278B, removing from the combined signal of each antenna branch its imaginary part, because imaginary part is an error term generated at channel estimation.

In a preferred embodiment, the RAKE receiver comprises a RAKE finger summer 280A combining the pilot signals of the RAKE fingers 270A, 270B, functioning by different delays, to a sum pilot signal representing the received pilot bits. This sum pilot signal can be brought to an estimator 282 of the signal-to-inference ratio, estimating the signal-to-interference ratio of said channel. The power control of a closed loop can be controlled by the obtained signal-to-interference ratio of said channel. This is illustrated in block 282 of Figure 2C by the text TPC (Transmission Power Control).

The invention is implemented preferably by software, at least part of the functions included in block 228 being changed to a software to be performed by a processor. However, the delay estimator 260 requiring a high calculation capacity is preferably implemented as an Application Specific Integrated Circuit (ASIC). The other functions included in block 228 can also be implemented by device solutions offering the needed functionality, such as an ASIC or a discrete logic.

A method of calculating weighting coefficients maximizing the SINR is presented next, assuming that the impulse response $\mathbf{h}$ of the channel and the covariance matrix $\mathbf{R}_{uu}$ of interference and noise are known. Subsequently, a method of estimating $\mathbf{h}$ and $\mathbf{R}_{uu}$ by means of known pilot bits included in a signal is presented. The presentation is a complex baseband signal model on symbol level for processing the signal. In the presentation, the bold face terms illustrate a vertical vector or a matrix. Let us assume that N multipath propagated Signals Of Interest (SOI) are found on time axis by matched filters, and each signal component is received via L separate antennas. The L complex channel taps of the Nth multipath propagated signal component are indicated by vectors $\mathbf{h}_n$ having a length L. The additive Multi Access Interference (MAI)

caused by other users, multipath self-interference and noise are indicated by a vector $\mathbf{u}_n$, which is modelled as an L-variate complex Gaussian distributed process with spatial possibly coloured covariance $\mathbf{R}_{uu,n} = E[\mathbf{u}_n\mathbf{u}_n^H]$. The signal received from the L antennas is indicated by a vector $\mathbf{r}_n$. An information symbol of the Mth user out of an alphabet of size M is indicated by the term s_m.

The Gaussian assumption for the despread MAI is valid for a great number of spreading factors having different lengths.

Subsequently, each symbol period is discretized into K samples, whereby the vector $\mathbf{r}_n$ can be presented in the form:

$$\mathbf{r}_n[k] = \mathbf{h}_n s_m[k] + \mathbf{u}_n[k], \quad k = 1,\ldots,K \qquad (1)$$

By stacking each of the N vectors to vectors having a length LN, a more compact notation is obtained:

$$\mathbf{r}[k] = \mathbf{h}\, s_m[k] + \mathbf{u}[k], \quad k = 1,\ldots,K \qquad (2)$$

The Gaussian distributed interference variables $\mathbf{u}_n[k]$ and $\mathbf{u}[k]$ are mutually uncorrelated across sampling instants and also across the different multipath propagated components of SOI. Then:

$$\mathbf{R}_{uu}[k] = E[\mathbf{u}[k]\mathbf{u}^H[k]] = diag(\mathbf{R}_{uu,1}[k],\ldots,\mathbf{R}_{uu,N}[k]) \qquad (3)$$

Assuming that the symbols s_m are equi-probable and the channel parameters $\mathbf{h}$ and the covariance matrix $\mathbf{R}_{uu}[k]$ of interference and noise are both known, the optimal demodulation involves the maximization of the log likelihood function ($|\cdot|$ denotes determinant):

$$\begin{aligned} L(\mathbf{r},\mathbf{s}_m) &= \ln\left(\prod_{k=1}^{K}\frac{1}{\pi^{LN}|\mathbf{R}_{uu}[k]|}\exp\{-\mathbf{u}[k]\mathbf{R}_{uu}^{-1}[k]\mathbf{u}^H[k]\}\right) \\ &= -\sum_{k=1}^{K}(\mathbf{r}[k]-\mathbf{h}s_m[k])^H\mathbf{R}_{uu}^{-1}[k](\mathbf{r}[k]-\mathbf{h}s_m[k]) + const_1 \end{aligned} \qquad (4)$$

Assuming that the symbols have the same energy, the formula 4 can be developed to the form:

$$L(\mathbf{r},\mathbf{s}_m)=\sum_{k=1}^{K}2\,\mathrm{Re}\left\{\mathbf{r}^H[k]\mathbf{R}_{uu}^{-1}[k]\mathbf{h}\;s_m[k]\right\}+const_2$$
$$=2\,\mathrm{Re}\left\{\sum_{k=1}^{K}\left(\sum_{n=1}^{N}\mathbf{w}_n^H[k]\mathbf{r}_n[k]\right)s_m^*[k]\right\}+const_2 \qquad (5)$$
$$=2\,\mathrm{Re}\left\{\mathbf{s}_m^H\;\mathbf{t}\right\}$$

whereby the N weighting coefficients minimizing the interference are $\mathbf{w}_n[k]=\mathbf{R}_{uu,n}^{-1}[k]\mathbf{h}_n$, and the vectors $\mathbf{s}_m$ and $\mathbf{t}$ have a length K with elements $s_m[k]$, respectively

$$\sum_{n=1}^{N}\mathbf{w}_n^H[k]\mathbf{r}_n[k].$$

Accordingly, the IRC RAKE receiver presented earlier can be decomposed into N temporal RAKE fingers, which each perform spatial IRC on the L antenna inputs by using weighting coefficients $\mathbf{w}_n[k]=\mathbf{R}_{uu,n}^{-1}[k]\mathbf{h}_n$. The outputs of the RAKE fingers are summed, i.e. combined, and a correlation detector is applied to determine for the symbol s_m a value enabling the largest symbol correlation metric.

If the multipath self-interference of SOI can be neglected, for instance when the processing gain is large enough, the $\mathbf{R}_{uu,n}$ is essentially the same in all N fingers, which means that it needs to be estimated and inverted only once. When the interference covariance matrix is spatially white, i.e. $\mathbf{R}_{uu,n} = \mathbf{Id}$, IRC becomes MRC, because $\mathbf{w}_n[k] = \mathbf{h}_n$. Direct Matrix Inversion (DMI) of the matrix $\mathbf{R}_{uu,n}$ can be avoided, if recursive algorithms, such as Least Mean Square (LMS) or Recursive Least Square (RLS), are used. Accordingly, the receiver can be constructed in such a way that the interference elimination method can be changed according to the circumstances between the MRC and IRC. When data transmission speeds are high, the interference is coloured, and therefore, IRC is used, and, respectively, MRC is used at low data transmission speeds. In principle, MRC is only one special case of IRC, which means that the method to be used can always be IRC.

Assuming that **h** and $\mathbf{R}_{uu}$ are not known, an unstructured Maximum Likelihood ML channel estimation of vector **h** and an estimation of the covariance matrix $\mathbf{R}_{uu}$ utilizing the performed channel estimation are presented next. As stated earlier, I/Q multiplexing is used in the uplink direction, the data channel being multiplexed to the branch I and the control channel to the branch Q. The control channel also comprises a previously known pilot part. Both channels can be separated from each other by despreading with orthogonal spreading codes. The symbol-level signal model is obtained from equation 1, by writing it separately for each part, I and Q, using BPSK symbols $s_m \in \{-1,1\}$. It is further assumed that the index k now refers to the bit index of the symbol sequence. K bits of DPCCH are collected into one slot.

Previously, the channel parameters **h** and the interference covariance $\mathbf{R}_{uu}$ were assumed known. Now, it is assumed that no a priori information on either spatial structure is available, which means that the optimal channel estimates are created on the maximum likelihood principle. The vector **r**[k], k=1,...,K and the pilot bits $s_p[k]$ of the DPCCH within one slot are used, by which ML estimates $[\hat{\mathbf{h}}, \hat{\mathbf{R}}_{uu}]$ are generated, being the joint minimizers of the log likelihood function:

$$
\begin{aligned}
&L(\mathbf{r};\mathbf{h},\mathbf{R}_{uu})= \\
&=\ln\left(\prod_{k=1}^{K}\frac{1}{\pi^{LN}|\mathbf{R}_{uu}[k]|}\exp\left\{-(\mathbf{r}[k]-\mathbf{h}s_p[k])^H\mathbf{R}_{uu}^{-1}[k](\mathbf{r}[k]-\mathbf{h}s_p[k])\right\}\right) \\
&=-\ln\left|\mathbf{R}_{uu}^{-1}\right|-trace\left\{\mathbf{R}_{uu}\frac{1}{K}\sum_{k=1}^{K}(\mathbf{r}[k]-\mathbf{h}s_p[k])\right\}+const_1
\end{aligned}
\qquad (6)
$$

This ML estimating problem is separable. When ML is given the estimate $\hat{\mathbf{h}}$, the vector will be $\hat{\mathbf{R}}_{uu}$:

$$
\hat{\mathbf{R}}_{uu}=\frac{1}{K}\sum_{k=1}^{K}(\mathbf{r}[k]-\hat{\mathbf{h}}s_p[k])(\mathbf{r}[k]-\hat{\mathbf{h}}s_p[k])^H \qquad (7)
$$

and the ML estimate $\hat{\mathbf{h}}$ is obtained as minimizer of the cost function ($|\cdot|$ denotes determinant):

$$F = \left| \frac{1}{K} \sum_{k=1}^{K} (\mathbf{r}[k] - \mathbf{h}s_p[k])(\mathbf{r}[k] - \mathbf{h}s_p[k])^H \right| \qquad (8)$$
$$= \left| (\mathbf{h} - \hat{\mathbf{r}}_{sr}^H)(\mathbf{h} - \hat{\mathbf{r}}_{sr}^H)^H + \hat{\mathbf{R}}_{rr} - \hat{\mathbf{r}}_{sr}^H \hat{\mathbf{r}}_{sr} \right|$$

where $\hat{\mathbf{r}}_{sr} = \frac{1}{K} \sum_{k=1}^{K} s_p[k]\mathbf{r}^H[k], \quad \hat{\mathbf{R}}_{rr} = \frac{1}{K} \sum_{k=1}^{K} \mathbf{r}[k]\mathbf{r}^H[k]$

F is minimized for the choice:

$$\mathbf{h} = \hat{\mathbf{r}}_{sr}^H \qquad (9)$$

A linear channel estimator based on pilot bits has been described above. It is obvious to one skilled in the art that known more developed channel estimation methods, such as methods utilizing data channel as well, can be applied to the method of the invention.

In the radio system described, there may occur interference caused by the frequency band adjacent to the wanted channel in some situations, this interference being known as Adjacent Channel Power (ACP). The adjacent frequency band may be the WCDMA frequency band adjacent to said operator, the WCDMA frequency band of another operator or a frequency band of some other system, for instance GSM system. The problem may cause blocking in the cell in the uplink direction. For instance, let us assume that a high efficiency GSM transmitter causes ACP to a RAKE receiver operating at a high data speed, i.e. at a low spreading ratio, on a 5 MHz frequency band, for instance. The ACP (as interference in general) must be above the noise level so that it can be eliminated. In accordance with the invention, an interference signal generated by the interference estimator 272 then comprises interference caused by the adjacent frequency band of the wanted channel, i.e. adjacent channel power, the detrimental effect of which can thus be eliminated. A shrinking of the cell on account of ACP can thus be prevented.

Though the invention has been described above with reference to the example of the attached drawings, it is clear that the invention is not restricted to that, but can be modified in many ways within the scope of the inventive idea of the attached claims.

CLAIMS

1. A RAKE receiver, comprising:

at least two antenna branches (232A, 232B) for receiving a radio signal;

at least one RAKE finger (270A, 270B) connected to the antenna branches (232A, 232B) for processing a multipath propagated signal component of the radio signal;

a delay estimator (260) connected to the antenna branches (232A, 232B) for searching for a delay of at least one multipath propagated signal component and for allocating a RAKE finger (270A, 270B) for processing the found multipath propagated signal component and for informing said RAKE finger (270A, 270B) of the found delay;

the RAKE finger comprising:

a channel estimator (272) for generating an impulse response of the channel of the multipath propagated signal component found by means of a known pilot part included in the radio signal of each antenna branch (232A, 232B);

an interference estimator (272) for generating an interference signal, included in the radio signal of each antenna branch (232A, 232B) and consisting of interference and noise, by subtracting from the received radio signal a regenerated wanted radio signal, which regenerated wanted radio signal is obtained by means of the known pilot part and the estimated impulse response of the channel;

a despreader (276A, 276B) connected to each antenna branch (232A, 232B) for despreading the pilot part (274A) included in the multipath propagated signal component by using a known spreading code by a delay informed by the delay estimator (260);

a despreader (276C, 276D) connected to each antenna branch (232A, 232B) for despreading the data part (274B) included in the multipath propagated signal component by using the known spreading code by a delay informed by the delay estimator (260),

characterized in that

the RAKE finger (270A, 270B) also comprises:

a weighting coefficient part (272) for providing each antenna branch (232A, 232B) with weighting coefficients maximizing the Signal-to Interference-and-Noise Ratio (SINR);

a multiplier (284A, 284B) for multiplying the pilot part (274A), despread by the despreader (276A, 276B) in each antenna branch (232A, 232B), by a weighting coefficient;

a multiplier (284C, 284D) for multiplying the data part (274B), despread by the despreader (276C, 276D) in each antenna branch (232A, 232B), by a weighting coefficient;

an antenna branch summer (278A) for combining the despread pilot parts (274A), received via the separate antenna branches (232A, 232B) and multiplied by the weighting coefficient, to one pilot signal;

an antenna branch summer (278B) for combining the despread data parts (274B), received via the separate antenna branches (232A, 232B) and multiplied by the weighting coefficient, to one data signal;

and the RAKE receiver further comprises a RAKE finger summer (280B) for combining the data signals of the RAKE fingers (270A, 270B) operating by different delays to a sum data signal representing the received bits.

2. A RAKE receiver according to claim 1, **characterized** in that it comprises a RAKE finger summer (280A) for combining the pilot signals of the RAKE fingers (270A, 270B) operating by different delays to a sum pilot signal representing the received pilot bits.

3. A RAKE receiver according to claim 2, **characterized** in that the sum pilot signal is brought to an estimator (282) of the signal-to-interference ratio, estimating the signal-to-interference ratio of the channel.

4. A RAKE receiver according to claim 3, **characterized** in that the power control of a closed loop is controlled by the obtained signal-to-interference ratio of said channel.

5. A RAKE receiver according to claim 1, **characterized** in that the delay estimator (260) comprises:

a matched filter (262A, 262B) for each antenna branch (232A, 232B) for performing a predetermined number of parallel correlation calculations for the received radio signal by different delays, whereby the pilot part included in the received radio signal is despread at correlation calculation by a known spreading code by using a predetermined delay;

an allocator (264) for selecting for each antenna branch (232A, 232B) on the basis of the correlations calculated at least one delay, by which the multipath propagated signal component is received, and for allocating the RAKE finger (270A, 270B) by informing it of the found delay.

6. A RAKE receiver according to claim 1, **characterized** in that, to provide antenna gain, the antenna branches (232A, 232B) form an antenna array, by which an antenna beam is formed into the desired direction by phasing separate antenna signals.

7. A RAKE receiver according to claim 1, **characterized** in that the antenna branches (232A, 232B) are diversity branches.

8. A RAKE receiver according to claim 1, **characterized** in that the antenna branches (232A, 232B) are antennas implemented by space diversity.

9. A RAKE receiver according to claim 1, **characterized** in that the antenna branches (232A, 232B) are antennas implemented by polarization diversity.

10. A RAKE receiver according to claim 1, **characterized** in that the channel estimator (272) performs the channel estimation on the optimal Maximum Likelihood principle.

11. A RAKE receiver according to claim 1, **characterized** in that weighting coefficients maximizing the signal-to-interference-and-noise ratio are formed for each antenna branch (232A, 232B) by multiplying an inverse matrix of a covariance matrix, generated of an interference signal of the antenna branches (232A, 232B), by an estimated impulse response of the channel.

12. A RAKE receiver according to claim 11, **characterized** in that a channel estimate generated by the optimal Maximum Likelihood method is utilized for estimating the covariance matrix generated of interference and noise.

13. A RAKE receiver according to claim 1, **characterized** in that the interference signal generated by the interference estimator (272) comprises interference caused by the adjacent frequency band of the wanted channel, i.e. adjacent channel power.

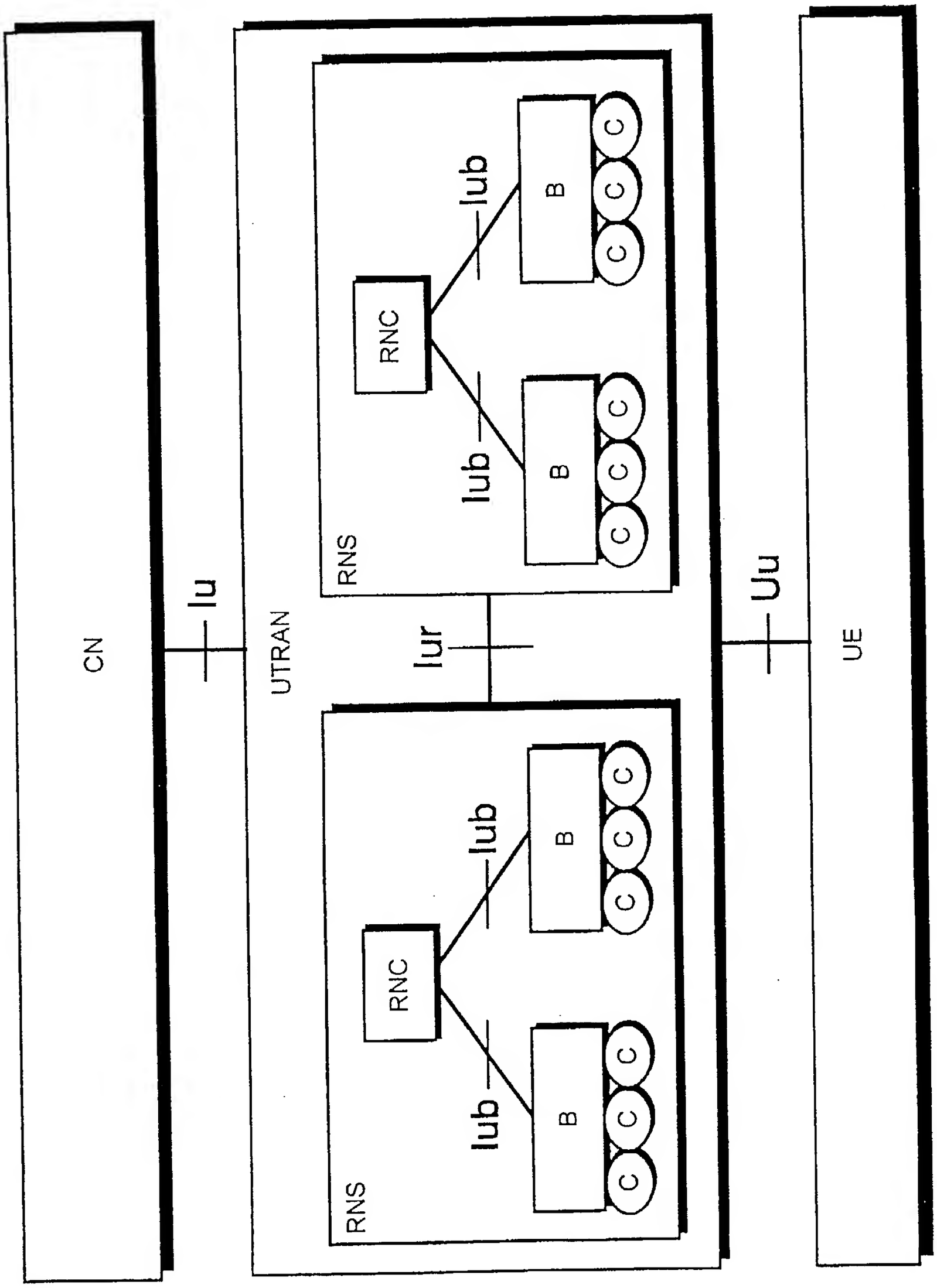


Fig 1A

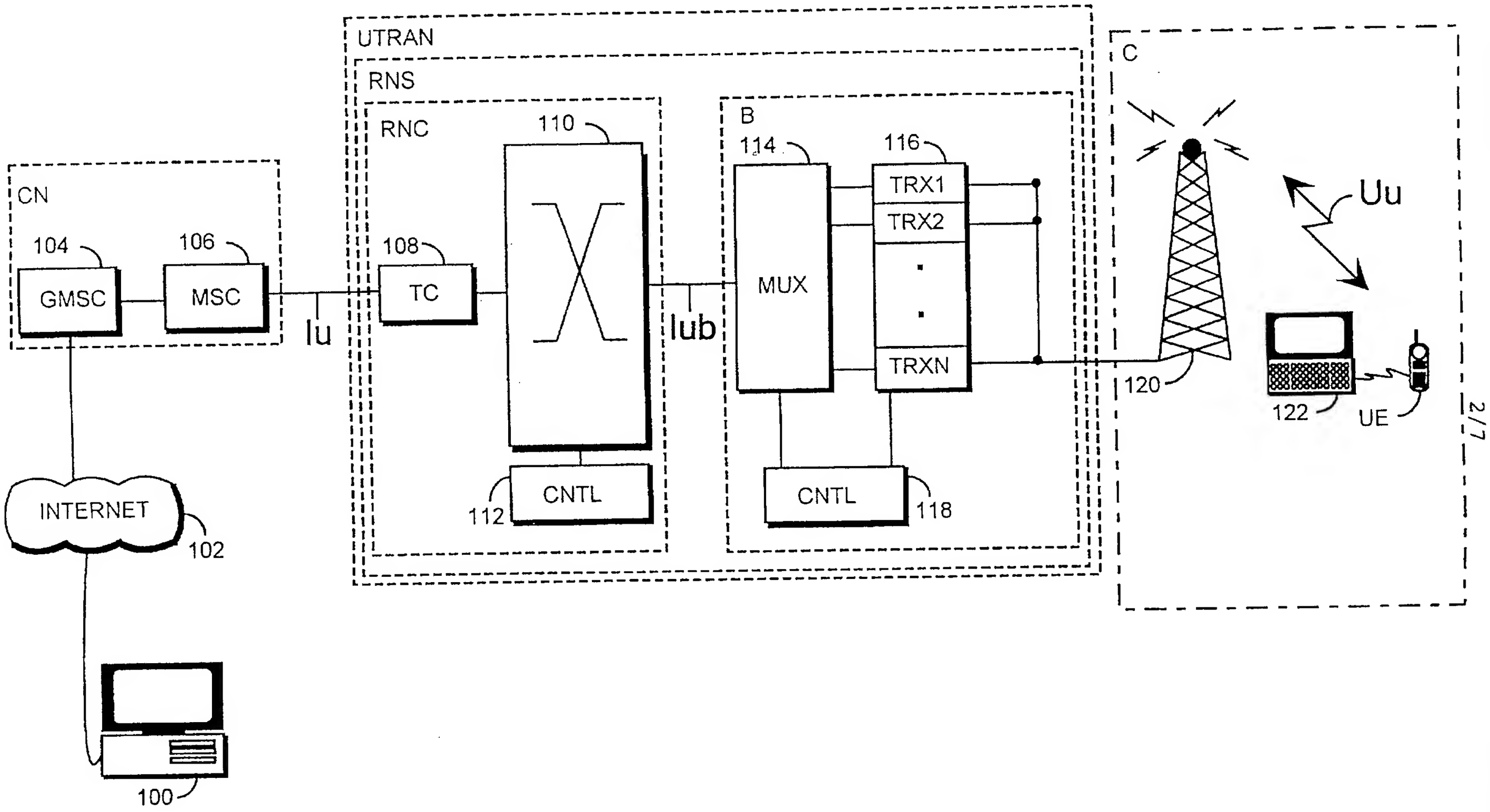
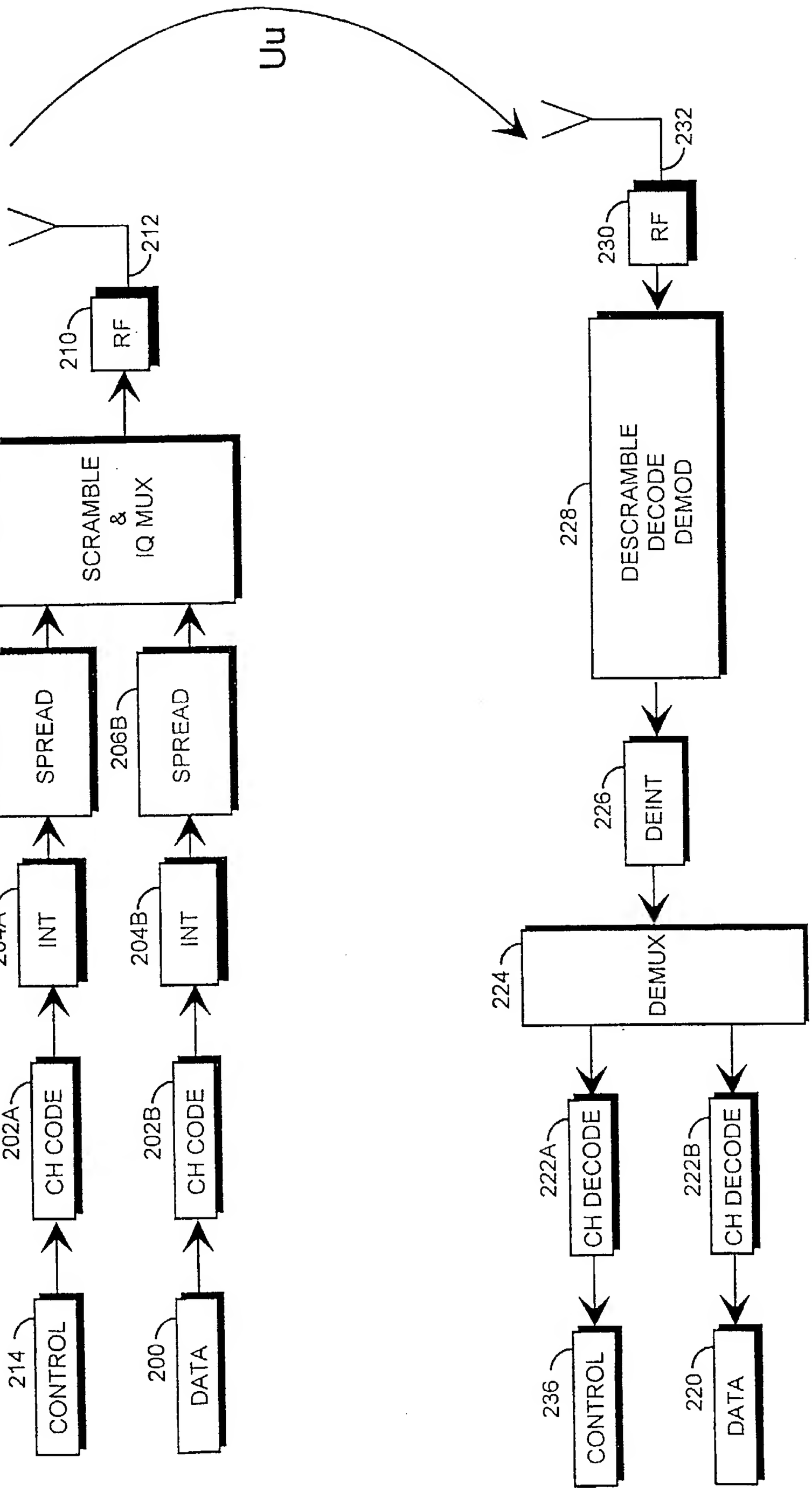


Fig 1B

PCT/FI99/00749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204B
CH DECODE
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DATA
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Fig 2A

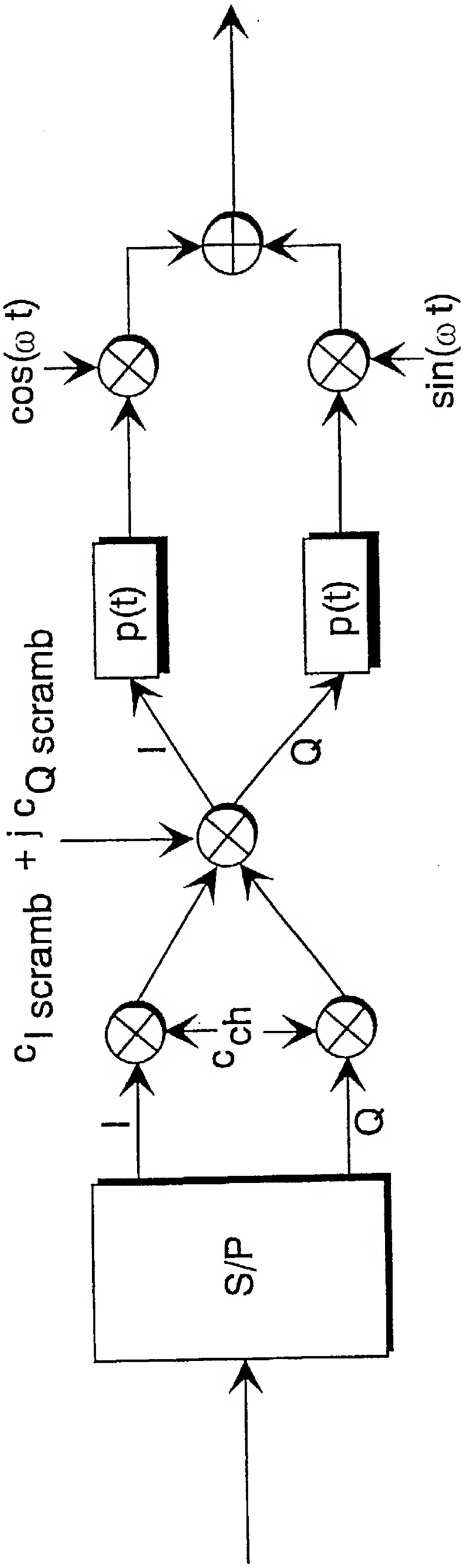


Fig 2B

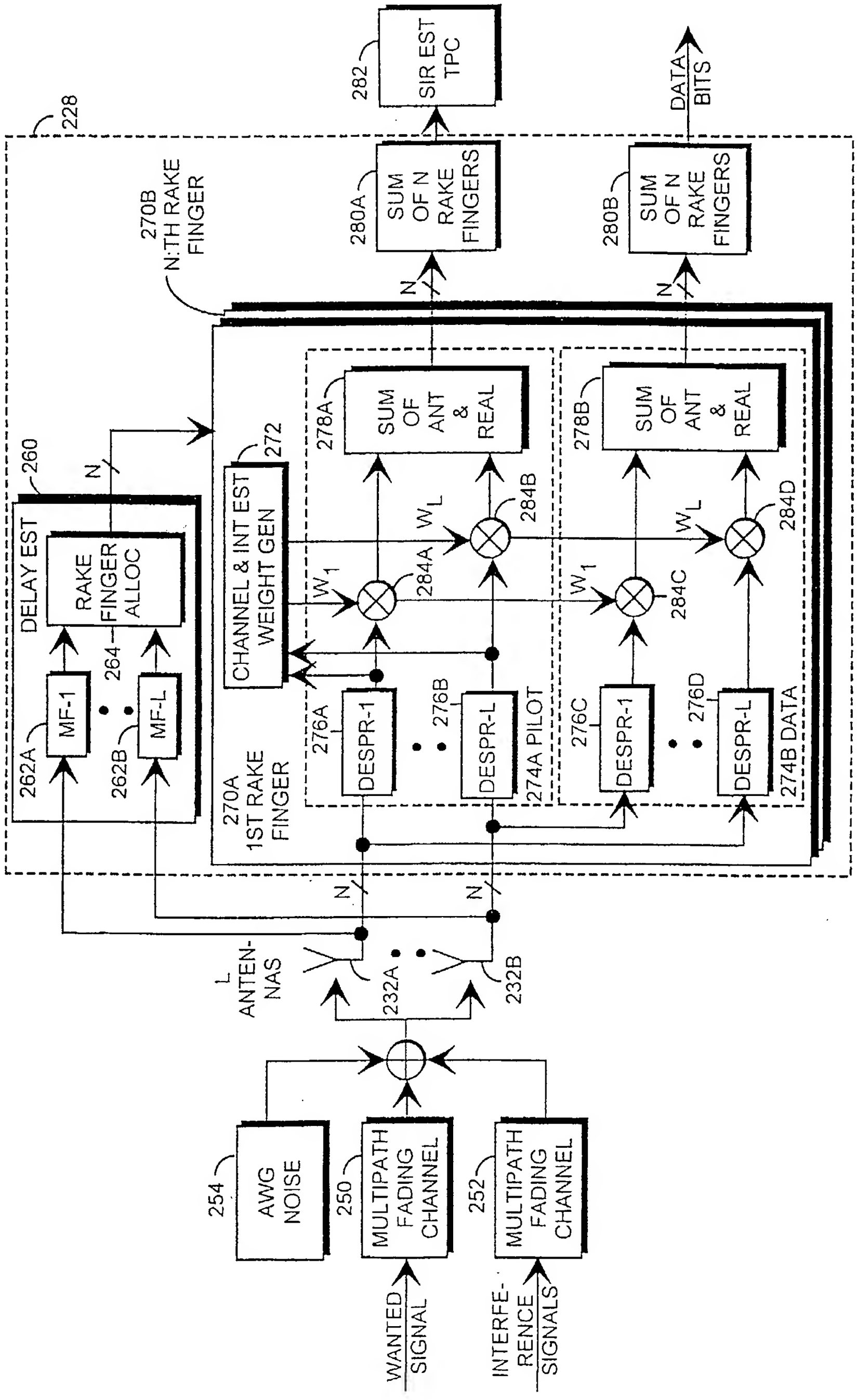
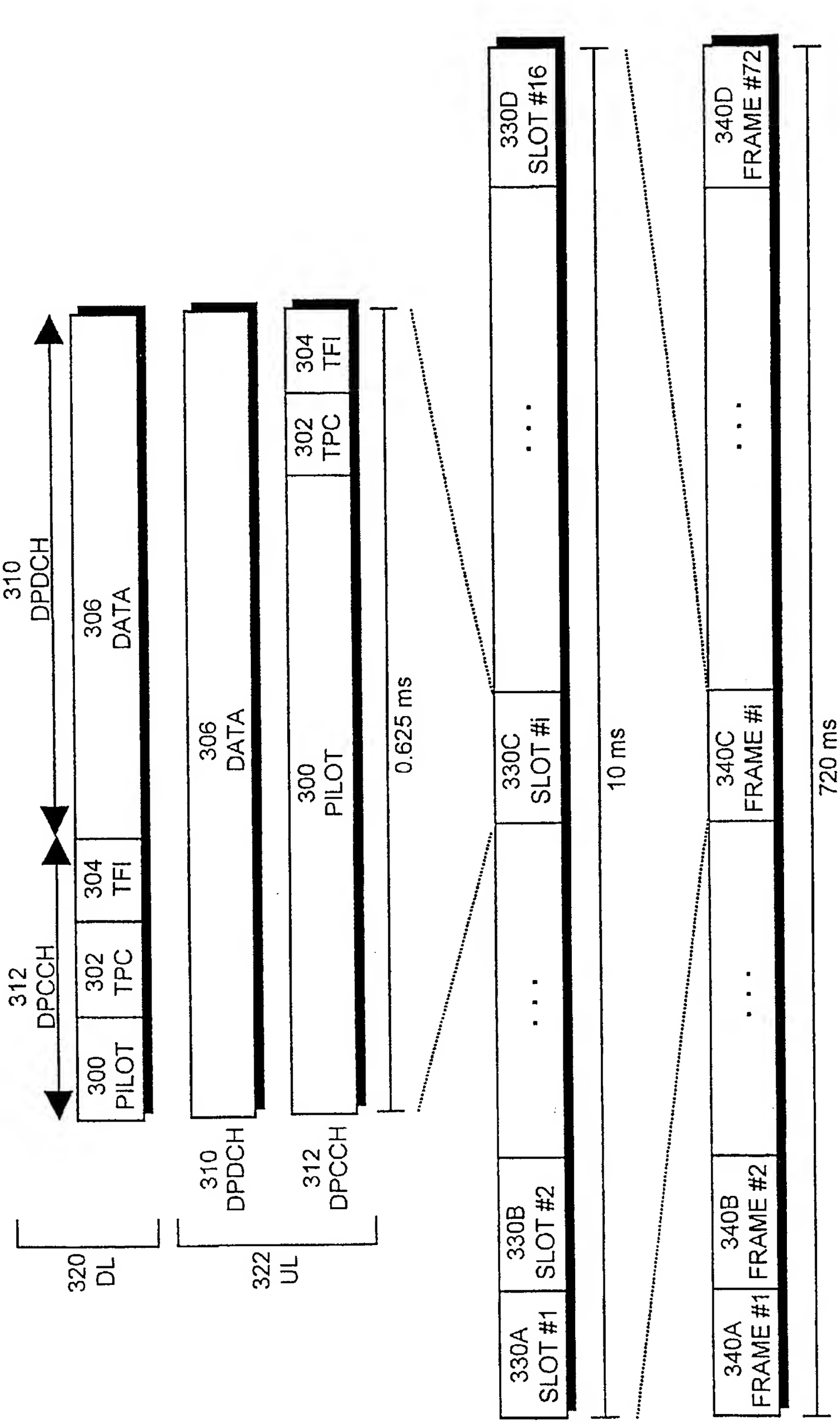

228
282
SIR EST TPC
DATA BITS
270B N:TH RAKE FINGER
280A SUM OF N RAKE FINGERS
280B SUM OF N RAKE FINGERS
N
260
DELAY EST
RAKE FINGER ALLOC
MF-1
MF-L
262A
262B
264
272
CHANNEL & INT EST WEIGHT GEN
278A SUM OF ANT & REAL
278B SUM OF ANT & REAL
W_1
W_L
284A
284B
284C
284D
276A DESPR-1
276B DESPR-L
276C DESPR-1
276D DESPR-L
270A 1ST RAKE FINGER
274A PILOT
274B DATA
L ANTEN-NAS
232A
232B
254 AWG NOISE
250 MULTIPATH FADING CHANNEL
252 MULTIPATH FADING CHANNEL
WANTED SIGNAL
INTERFE-RENCE SIGNALS

Fig 2C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TFI
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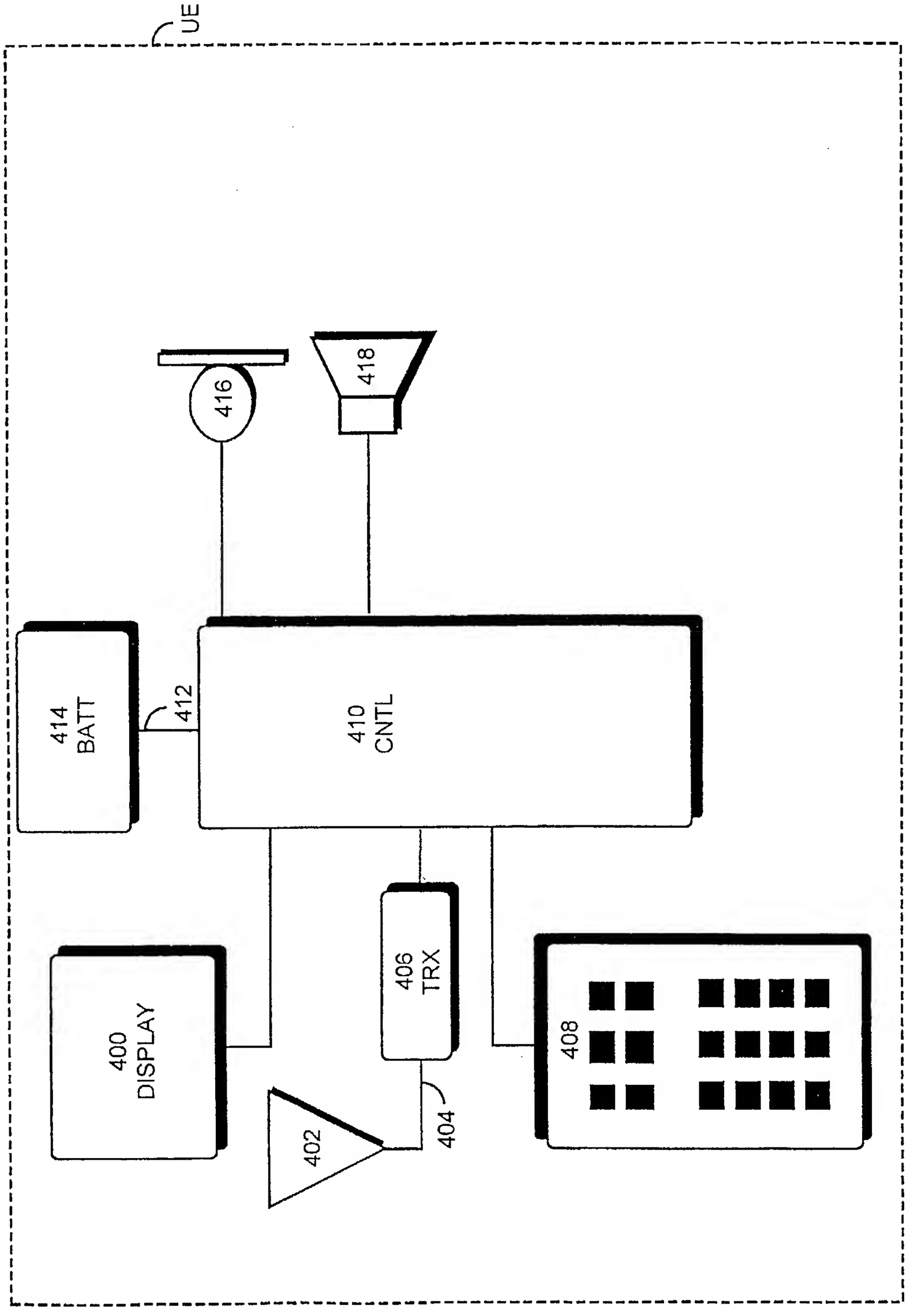
SLOT #1
330B
SLOT #2
330C
SLOT #i
330D
SLOT #16
340A
FRAME #1
340B
FRAME #2
340C
FRAME #i
340D
FRAME #72

Fig 3


UE
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BATT
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CNTL
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DISPLAY
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TRX
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404
408

Fig 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 99/00749

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H04B 1/69
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	EP 0825727 A1 (NTT MOBILE COMMUNICATIONS NETWORK INC.), 25 February 1998 (25.02.98), abstract ---	1-19
A	US 5680419 A (GREGORY E. BOTTOMLEY), 21 October 1997 (21.10.97), abstract --- --------	1-19

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 February 2000	24 -02- 2000
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Rune Bengtsson/mj Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

02/12/99

International application No.
PCT/FI 99/00749

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